## *Chapter 6*

# Risk assessment of rodenticides through use of telemetry and other methods: 5 examples

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*Note: These studies were conducted by the Denver Wildlife Research Center (DWRC) when it was part of the U.S. Department of the Interior, U.S. Fish and Wildlife Service. The DWRC was transferred to the U.S. Department of Agriculture, Animal and Plant Health Inspection Service in 1985.*

Radiotelemetry is an important tool used for monitoring both the effectiveness and the nontarget hazards associated with use of rodenticides. This chapter discusses 5 large-scale field studies conducted by the DWRC over the last 15 years. Various techniques were used to assess efficacy, including direct methods for censusing populations (telemetry and visual counts) and indirect methods (active burrow counts and mound counts). Several methods were used also to assess nontarget hazards to mammals and birds, including radiotelemetry, carcass searches, sightings of marked individuals, mark-recapture trapping, and nest surveys. The use of radiotelemetry for certain species, but not others, in these studies is discussed. The discussion also focuses upon the problems associated with radiotelemetry and its relationship to risk assessment. Of critical importance to the performance of effective field trials is the ability to obtain laboratory toxicology information on potential nontarget species before proceeding to the field; this assures that the species chosen for study will be those at greatest risk.

Prior to the formation of the U.S. Environmental Protection Agency (USEPA) in 1972, many pesticides were registered without extensive data on efficacy and potential hazards to wildlife. Of particular concern to the USEPA were the acutely toxic vertebrate pesticides, which were known to be toxic to a broad spectrum of wildlife. In 1973, the USEPA planned to hold formal hearings to determine whether the uses of some rodenticides should be canceled or amended to reduce nontarget risks. However, during prior informal hearings, the USEPA determined that additional scientific information was needed on rodenticides, particularly on the efficacy to target species and the hazards to nontarget wildlife; therefore, the formal hearings were canceled. Because very little wildlife toxicology information had been submitted for the most widely used field rodenticides such as strychnine, 1080, and zinc phosphide, the USEPA solicited information on these compounds. In June 1974, an interagency agreement between the USEPA and the U.S. Fish and Wildlife Service (USFWS) through the DWRC was signed to conduct field studies with these rodenticides. The goal was to develop data on the extent of unintentional poisoning of nontarget wildlife species. Over the next decade, the DWRC conducted a series of field studies, using USEPA and USFWS funds, designed to obtain information about target efficacy and nontarget mortality during operational use of strychnine, 1080 (sodium monofluoroacetate), and zinc phosphide rodenticides. Evaluation of these studies and their methodology formed the basis for the field study guidelines developed in 1988 by the USEPA.

The 1988 Terrestrial Field Study guidelines (Fite et al. 1988) include 2 types of field studies for wildlife—screening and definitive. The screening study grossly determines effect versus no effect. In contrast, the definitive study quantifies the magnitude of effects previously identified. The studies conducted by the DWRC and discussed in this chapter are primarily screening studies because they assess the potential for acute toxic effects (such as direct poisoning and death) and immediate sublethal toxic effects that might affect behavior and survival and do not necessarily quantify risk. Although risks are quantified for some wildlife species, these studies do not fit the guideline definition of "definitive studies" (Fite et al. 1988) for 2 reasons. First, definitive studies are designed as manipulative experiments with control and treated plots to allow quantification of the magnitude of mortality, reproductive effects, and long-term survival; in contrast, most of the DWRC studies were designed as observational studies to assess acute mortality to wildlife species following an operational treatment of a rodenticide. Second, definitive studies monitor treatment effects on only one or a few species that are already believed to be affected; the DWRC studies were designed to monitor a number of species to determine those at risk from the pesticide application. In addition, the studies were conducted at only 1 site, rather than at 8 to 14 sites, as recommended by the USEPA guidelines.

In this chapter, we describe 5 large-scale rodenticide field studies conducted by the DWRC since 1975: 1) hazards to seed-eating birds and other wildlife associated with surface strychnine baiting for Richardson's ground squirrels *(Spermophilus richardsonii)*, 2) and 3) hazards to wildlife associated with underground strychnine baiting for pocket gophers *(Thomomys talpoides)* using a burrow builder versus handbaiting, 4) hazards to pheasants *(Phasianus colchicus)* and cottontail rabbits *(Sylvilagus floridanus)* associated with zinc phosphide baiting for microtine rodents (*Microtus* spp.) in orchards, and 5) hazards to wildlife associated with 1080 baiting for California ground squirrels *(Spermophilus beecheyi)*. Techniques used to assess rodenticide efficacy against the target species included direct methods for censusing populations (telemetry and visual counts) and indirect methods (active burrow counts and mound counts). Methods used to assess nontarget hazards to mammals and birds included telemetry, carcass searches, sightings of marked individuals, mark-recapture trapping, and nest surveys. This chapter emphasizes telemetry as an important tool for monitoring both the effectiveness and nontarget hazards associated with use of rodenticides.

All radio transmitters used in the studies (except those used on chipmunks in Study 3) were designed and built by the DWRC Electronics Laboratory in the 164 MHZ band.

Radio-equipped animals were followed using mobile radio-tracking vehicles equipped with roof-mounted, dual yagi antennas and voice radio communication systems (Hegdal and Gatz 1978; Hegdal and Colvin 1986). The antennas could be rotated from inside the vehicle, and radio bearings were indicated on a 360° protractor by a pointer attached to the antenna mast. Coaxial cables from the antenna were attached to a hybrid junction box, which allowed switching from in-phase to out-of-phase (null) operation. We used Model LA12 receivers (built by AVM Instrument Co., Champaign, Illinois) for all radio tracking. Hand-held loop and yagi antennas were employed for portable field use. Animal locations were determined in 1 of 4 ways: 1) hand tracking by walking out the radio-equipped animal using a receiver and hand-held antenna, 2) vehicle tracking using 2 vehicles and obtaining simultaneous bearings from 2 vehicles parked at previously mapped locations, 3) vehicle tracking using 1 vehicle by plotting a bearing to the animal and a second bearing to a beacon transmitter, and 4) aerial searches for missing or lost animals.

## Hazards to seed-eating birds and other wildlife associated with surface strychnine baiting for Richardson's ground squirrels

Strychnine is an acutely toxic rodenticide with LD50s to mammals of 0.7 to 27 mg/kg and to birds of 2.9 to 161 mg/kg (LaVoie unpublished data). The DWRC evaluated wildlife hazards associated with surface baiting with strychnine for Richardson's ground squirrels on rangeland in south-central Wyoming (Hegdal unpublished data). In this area, cattle ranching and farming are the principal agricultural activities; ground squirrels compete with livestock for forage and can cause considerable damage to agricultural crops adjacent to rangeland. During late April and early May 1976, approximately 3650 ha were treated with 0.5% strychnine-treated oats to reduce damage caused by ground squirrels. Approximately 1 tablespoon of bait was placed at or near each ground squirrel burrow. Application rate varied between 1 and 2 kg/ha. Treated areas were scattered between Saratoga and Encampment, Wyoming.

The reduction in ground squirrel populations was measured on 6 randomly selected plots by plugging ground squirrel burrows then recording the number reopened after 48 h; the procedure was conducted immediately before treatment, 3 d after treatment, and 1 month after treatment. Effectiveness varied, with some plots showing almost no reduction in ground squirrel populations while others indicated up to 85% control ($\bar{x}$ = 2.8%). Chi-square analysis showed a significant change in populations after treatment on all but 2 plots. During carcass searches on 19.5 ha, an average of 3.5 dead ground squirrels/ha were located above ground; carcasses were left undisturbed to allow assessment of secondary risks of strychnine poisoning to mammalian predators and raptors. Residue analyses were conducted to confirm cause of death for predators and raptors.

Nontarget small mammal populations were censused by live trapping before and after treatment. Because populations were low and numbers trapped were probably inadequate to detect significant treatment effects, no conclusions can be drawn about strychnine effects on small mammals.

Previous studies had shown evidence of hazards to some seed-eating birds at strychnine baiting sites (Rudd and Genelly 1956; Hegdal and Gatz 1976), so an extensive literature search was conducted to determine focal species. Based on this search, we evaluated risk to mourning doves *(Zenaida macroura)* by radiotelemetry, to horned larks *(Eremophila alpestris)* by marking, and to other seed-eating birds by carcass searches conducted intensively on 19.5 ha for 14 d after treatment. Mortality of mourning doves was assessed by radiotelemetry because these birds can move great distances and would be difficult to census by mark-recapture techniques. We captured 84 mourning doves using Kniffin collapsible bait traps (Reeves et al. 1968) and 3-cell Potter traps. We attached colored and numbered leg streamers to birds to facilitate locating individuals. We also attached a radio transmitter by gluing the transmitter to either a latex rubber harness or a 3 × 3-cm latex rubber patch that was then glued to clipped feathers on the dove's back. The latex degraded in sunlight, and transmitters dropped off birds after 30 d to 3½ months. Most transmitters quit functioning after 3 to 4 weeks, but a few functioned for up to 3 months. Of the 84 radio-equipped doves, 59 were followed through treatment: 36 (61%) of these survived the treatment or died of causes unrelated to treatment (16 survived, while 20 either were killed by predators, died in untreated areas and did not use treated areas, or contained no strychnine residues); 23 (39%) died in or near treated areas and/or contained strychnine residues (Table 6-1), providing a quantitative estimate of risk. Dead doves were also located during carcass searches up to 80 d after treatment at an average of 1.1 dead doves/ha searched. In addition to structured carcass searches, we sometimes found dead doves while following radio-equipped birds; in one instance, 40 dead doves were found along one-half mile of fence; those analyzed contained strychnine residues (Table 6-2). The carcass search information could not be used to quantify risk because pretreatment densities of doves were not available.

Horned larks using areas near ground squirrel burrows were considered to be at risk; we therefore trapped 19 male horned larks on their territories using 3-cell Potter traps with a decoy horned lark in the center cell. Horned larks were too small to carry currently available transmitters for any length of time; therefore, they were marked with leg streamers. Because they are territorial during the breeding season, censuses on territories were made before and after treatment, and carcass searches were conducted on horned lark territories after treatment to quantify risk. As an additional measure of risk, we compared the number of larks trapped in control and treated areas after treatment. Populations of horned larks on treated areas were significantly affected. Of the 19 marked horned larks, 6 disappeared before treatment. An additional 3 were not observed after treatment, and their fate was unknown. Six of the remaining 10 (60%) marked territorial horned larks were killed by the bait (verified by residue analysis) between 1 and 18 d after treatment. During carcass searches on 19.5 ha, we found an average of 2.5 dead horned larks/ha. Pretreatment densities were estimated at 2.5 to 3.0 larks per ha; almost all of

*Table 6-1 Summary of results from strychnine residue analysis of 27 radio-equipped mourning doves found dead in and near treated areas. Mourning doves did not arrive in Wyoming until May, after the baiting*

| # days tracked | Tracked in treated area | Dead # days posttreatment | Cause of death | Strychnine residue ppm | Part analyzed[a] |
|---|---|---|---|---|---|
| 1 | No | 17 | Bait | 11.2 | GI |
| 1 | Yes | 21 | Bait | 146 | GI |
| 1 | No | 22 | Unknown | NLT 0.5[b] | GI |
| 2 | Yes | 17 | Bait | 19 | GI |
| 4 | No | 14 | Bait | 96 | GI |
| 4 | Yes | 15 | Bait | 51 | GI |
| 5 | No | 46 | Probable bait kill | B | B |
| 6 | Yes | 64 | Bait | 8.2 | GI |
| 7 | Yes | 55 | Probable bait kill | B | B |
| 8 | Yes | 43 | Possible predator kill | B | B |
| 9 | Yes | 29 | Unknown | NLT 0.5 | GI |
| 9 | Yes | 55 | Bait | 3.9 | IO |
| 10 | Yes | 54 | Bait | 5.6 | GI |
| 11 | Yes | 21 | Unknown | NLT 0.5 | GI |
| 15 | Once | 36 | Bait | 25 | GI |
| 16 | Yes | 51 | Bait | <0.5[c] | WB |
| 20 | Yes | 35 | Bait | 5.5 | GI |
| 21 | Yes | 36 | Probable bait kill | B | B |
| 22 | Yes | 33 | Bait | 62 | GI |
| 22 | Yes | 71 | Probable bait kill | B | B |
| 22 | Yes | 85 | Probable bait kill | B | B |
| 27 | Yes | 48 | Bait | 8.6 | GI |
| 30 | Yes | 50 | Bait | 0.96 | GI |
| 32 | Yes | 60 | Bait | <0.5 | WB |
| 34 | Once | 47 | Probable bait kill | B | B |
| 36 | Yes | 58 | Bait | 1.2 | WB |
| 51 | Yes | 101 | Probable bait kill | B | B |

[a] Parts analyzed are as follows: GI – Gastrointestinal tract; IO – Internal organs; WB – Whole body;
[b] NLT 0.5 – Not found, if present less than 0.5 ppm
[c] < 0.5 – Found, but less than 0.5 ppm

the lark population was killed on treated areas. One bird was found dead 71 d after treatment. Table 6-2 contains strychnine residue levels for dead horned larks. On control areas, we trapped a mean of 10.5 birds per 100 trap-hours versus 0.87 per 100 trap-hours on treated areas, a highly significant difference (chi-square, $P < 0.005$). The risk to local horned lark populations in baited areas is therefore great.

Populations of vesper sparrows *(Pooecetes gramineus)* were not as seriously affected. Two of 16 (12.5%) vesper sparrows marked with leg streamers before treatment were found dead 2 and 4 d after treatment and contained strychnine residues. Four vesper sparrows were found during carcass searches (0.2 birds/ha), and 2 contained strychnine residues;

*Table 6-2 Summary of results from strychnine residue analysis of nontarget animals found dead in treated areas*

| Species | # days posttreatment | Strychnine residue ppm | Part analyzed[a] |
|---|---|---|---|
| Mourning dove | 2 | 10.3 | GI |
| Mourning dove | 2 | 39 | " |
| Mourning dove | 4 | 4.6 | " |
| Mourning dove | 7 | 38 | " |
| Mourning dove | 7 | 48 | " |
| Mourning dove | 8 | 13 | " |
| Mourning dove | 8 | 49 | ' |
| Mourning dove | 11 | 36 | " |
| Mourning dove | 18 | NLT 0.5[b] | " |
| Mourning dove | 18 | 1.1 | " |
| Mourning dove | 18 | 3.6 | " |
| Mourning dove | 18 | 31 | Crop |
| Mourning dove | 18 | 43 | GI |
| Mourning dove | 28 | 4.3 | " |
| Mourning dove | 37 | 17 | " |
| Mourning dove | 42 | 1.1 | " |
| Mourning dove | 55 | NLT 0.5 | IO |
| Mourning dove | 55 | 1.0 | GI |
| Mourning dove | 55 | 6.4 | " |
| Mourning dove | 56 | 2.0 | " |
| Mourning dove | 56 | 3.9 | " |
| Mourning dove | 56 | 34 | " |
| Mourning dove | 59 | 8.0 | " |
| Mourning dove | 60 | 0.73 | " |
| Mourning dove | 60 | 17 | " |
| Mourning dove | 66 | 6.5 | " |
| Mourning dove | 80 | 82 | " |
| Horned lark | 1 | 5.7 | GI |
| Horned lark | 1 | 9.0 | " |
| Horned lark | 1 | 9.8 | " |
| Horned lark | 2 | 7.5 | " |
| Horned lark | 2 | 8.7 | " |
| Horned lark | 2 | 8.8 | " |
| Horned lark | 2 | 12 | " |
| Horned lark nestling | 2 | 24 | " |
| Horned lark | 3 | 4.2 | " |
| Horned lark | 4 | 5.9 | " |
| Horned lark | 18 | 2.1 | " |
| Horned lark | 33 | NLT 0.5 | " |
| Horned lark | 59 | 7.5 | ' |
| Horned lark | 59 | 8.7 | IO |

*Table 6-2 continued*

| Species | # days posttreatment | Strychnine residue ppm | Part analyzed[a] |
|---|---|---|---|
| Vesper sparrow | 2 | NLT 0.5 | GI |
| Vesper sparrow | 4 | 7.1 | " |
| Vesper sparrow | 4 | 39 | " |
| Red-winged blackbird | 2 | 6.4 | GI |
| Red-winged blackbird | 3 | 4.3 | " |
| Red-winged blackbird | 3 | 7.1 | " |
| Red-winged blackbird | 3 | 19 | " |
| Red-winged blackbird | 5 | 5.1 | " |
| Brewer's blackbird | 1 | 31 | GI |
| Brewer's blackbird | 2 | 0.67 | " |
| Brewer's blackbird | 4 | 52 | " |
| Brewer's blackbird | 67 | 0.7 | IO |
| Yellow-headed blackbird | 0 | 5.9 | GI |
| Yellow-headed blackbird | 1 | 0.89 | " |
| Yellow-headed blackbird | 4 | 42 | ' |
| Brown-headed cowbird | 7 | 9.5 | GI |
| Brown-headed cowbird | 67 | 4.4 | IO |
| Common crow | 2 | 1.3 | GI |
| Common crow | 80 | 1.0 | IO |
| Starling | 4 | 14 | IO |
| Savannah sparrow | 20 | 43 | GI |
| Meadowlark | 10 | 23 | GI |
| Meadowlark | 21 | 2.0 | WB |
| Meadowlark nestling | 38 | NLT 0.5 | GI |
| Meadowlark nestling | 38 | " | " |
| Meadowlark nestling | 38 | " | " |
| Meadowlark nestling | 38 | " | " |
| Meadowlark nestling | 38 | " | " |
| Mallard | 1 | 0.68 | GI |

[a] Parts analyzed are as follows: GI – Gastrointestinal tract; IO – Internal organs
[b] LT 0.5 – Not found, if present less than 0.5 ppm.

however, a marked reduction in vesper sparrow populations was not immediately observed.

Blackbirds were killed early in the season while migrating through the study area. During carcass searches we located 18 (0.9/ha) red-winged blackbirds *(Agelaius phoeniceus)*, 21 (1.1/ha) Brewer's blackbirds *(Euphagus cyanocephalus)*, 6 (0.3/ha) yellow-headed blackbirds *(Xanthocephalus xanthocephalus)*, 2 (0.1/ha) brown-headed cowbirds *(Molothrus ater)*, 1 (0.05/ha) common crow *(Corvus brachyrhynchos)*, 1 starling *(Sturnus vulgaris)*, 1 Savannah sparrow *(Passerculus sandwichensis)*, and 1 western meadowlark *(Sturnella neglecta)*. Those that could be tested all contained strychnine residues (Table 6-2). During radio tracking and other activities, we also found the following carcasses that contained strychnine residues: 4 Brewer's blackbirds, 5 red-winged blackbirds, and 1 mallard *(Anas platyrhynchos)*.

Previous literature indicates that strychnine does not cause significant secondary poisoning (Tucker and Crabtree 1970; Hegdal and Gatz 1978); however, because a potential hazard could exist for species with a low LD50 (Wood 1965; Tucker and Crabtree 1970. Consequently, we monitored secondary hazards to mammalian predators and raptors. Radiotelemetry is the only reliable method for relocating these highly mobile predators. Therefore, we captured 2 great horned owls *(Bubo virginianus)* and 1 badger *(Taxidea taxus)* that used treated areas and radio equipped them with mortality transmitters that emitted a faster signal when the animal had failed to move for a few hours. We did not detect any detrimental effects. The radio-equipped great horned owls used treated areas, fed on treated doves, and were alive 4 months after treatment. Other raptors were observed feeding on ground squirrels in the study area and were probably exposed to some level of strychnine; however, 8 active raptor nests monitored through treatment fledged young. We concluded that the strychnine bait posed minimal risk to predators.

Radiotelemetry in this study was invaluable for determining risks to seed-eating bird species, raptors, and mammalian predators. These animals moved widely and could not easily be monitored by other means. For territorial bird species, visual surveys and carcass searches on territories proved both feasible and economical. This study demonstrated minimal risk from above ground strychnine baiting to species other than seed-eating birds.

## Hazards to wildlife associated with underground strychnine baiting for pocket gophers

The following 2 studies, also conducted with strychnine alkaloid grain baits, illustrate the influence that use patterns can have in determining whether nontarget risks will occur. While the above ground baiting for ground squirrels used in the previous study produced significant seed-eating bird mortality, the below ground baiting used in the following 2 studies caused no significant risk to seed-eating birds.

***Burrow builder application***

Throughout the United States, pocket gophers cause extensive damage to agricultural crops by clipping vegetation and mound building (Luce and Case 1981). Because of this damage, below-ground baiting with strychnine to control pocket gopher populations is frequently employed. During spring and summer 1975, the DWRC evaluated the hazards to wildlife associated with strychnine baiting for plains pocket gophers *(Geomys bursarius)* (Rudd and Genelly 1956) using a burrow builder, which makes an artificial underground burrow into which the bait is deposited. The Sherburne National Wildlife Refuge in Minnesota was divided roughly in half to form control and treated areas, and we applied 0.5% strychnine-treated bait to pocket gopher occupied habitat on 662 ha of the treated area.

Strychnine was effective in controlling pocket gophers—activity plots using a closed-hole index (Hansen and Ward 1966) showed 88% reduction in activity. Populations of other small rodents, as shown by live trapping, were quite low pretreatment, but declined even further on the treated area ($P < 0.10$), yet significantly increased on the control area ($P < 0.001$), indicating some risk to nontarget rodents.

With the underground placement of bait, we expected primary hazards to seed-eating birds to be low. However, because small amounts of bait were occasionally available to birds through inadvertent spillage as the burrow builder tube was raised or lowered into the ground, we monitored red-winged blackbirds as a focal species for seed-eating birds. This species was chosen because it is territorial in cattail marshes during the breeding season and can be successfully monitored without the use of expensive transmitters. We trapped and marked 100 territorial males on both the treated and control areas and monitored their presence through the treatment. Although some treated grain was available on the surface and marked birds were observed feeding in treated fields, detrimental effects were not detected on red-winged blackbird populations. The number of territorial male red-winged blackbirds maintaining territories was slightly higher on the treated area ($P < 0.005$) compared to the control.

Pocket gophers are an important part of the diet of raptors during some periods of the year and can also form a high percentage of the diet of some mammalian predators. Therefore, secondary risk to these predators was studied. Because telemetry is the only reliable technique to monitor movement and mortality of highly mobile predators, we equipped 36 raptors and 36 mammalian predators with radio transmitters to measure potential secondary poisoning effects. Mortality transmitters were used on mammalian predators, which could accommodate the additional weight. Many animals left the area before treatment, had transmitters fail, or did not use treated areas. On the control area, 2 red-tailed hawks *(Buteo jamaicensis)*, 1 American kestrel *(Falco sparverius)*, 1 great horned owl, 5 badgers, 5 striped skunks *(Mephitis mephitis)*, and 1 red fox *(Vulpes fulva)* were tracked daily and survived for at least 3 weeks after the treatment period. On the treated area, 2 striped skunks, 3 badgers, 2 red foxes, and 1 coyote *(Canis latrans)* frequently used the treated areas; all survived at least 3 weeks after treatment. Use of radiotelemetry in this study allowed us to follow individuals for long periods of time: the transmitters functioned for 37 to 75 d on raptors, 89 to 132 d for skunks, and 77 to 143 d for larger mammalian predators. Radiotelemetry allowed us to conclude that secondary poisoning risks from underground baiting with strychnine to raptors and mammalian predators are nonexistent or low.

***Hand-baiting application***

Damage to conifer seedlings by pocket gophers is a major factor limiting reforestation on over 120,000 ha of forest land in the western United States (Northwest Forest Pocket Gopher Committee 1976). In conjunction with reforestation programs, the U.S. Forest Service (USFS) annually treats thousands of hectares with strychnine alkaloid-treated grain to control pocket gopher populations before tree planting. This has been shown to reduce pocket gopher damage to seedlings (Barnes 1974; Crouch and Frank 1979).

Because of USFS concerns that the underground application of strychnine bait could pose potential hazards to other species, we monitored an operational USFS baiting program conducted in 1979 on the Targhee National Forest, Idaho (Fagerstone et al. 1980). Our objectives were to assess the primary risks to nontarget small mammals (Fagerstone et al. 1980) and secondary risks to grizzly bears *(Ursus arctos horribilis)* (Barnes et al. 1985) resulting from hand baiting in underground pocket gopher burrow systems with strychnine alkaloid bait.

As in the previous study, live trapping was used to census small mammal populations, primarily deermice (*Peromyscus* spp.) on control and treated areas before and after baiting (Fagerstone et al. 1980); no significant differences occurred between pre- and post-treatment population estimates or between treated and untreated plots. Populations of chipmunks were too widely dispersed to monitor by means of trapping, so we used radiotelemetry to assess the hazards of strychnine baiting to yellow pine chipmunks *(Eutamias amoenus)*. Twenty-four chipmunks and 1 flying squirrel *(Glaucomys sabrinus)* were radio equipped and their movements monitored daily on treated areas throughout treatment using hand-held yagis and receivers. Transmitters (SM1 and SM1 mouse style with a collar attachment) were built by AVM Instrument Co., weighed between 2.5 and 5.8 g, and had a battery life of 2 to 4 weeks. Three of the 24 chipmunks died after treatment; all were scavenged by predators, and 2 contained low levels of strychnine residues (0.29 and 0.35 ppm), indicating potential risk from the strychnine. Assuming strychnine contributed to the 2 deaths, the 4.2% mortality rate did not have a significant effect on the chipmunk population.

To investigate potential hazards of secondary poisoning to grizzly bears associated with feeding on dead pocket gophers, we radio equipped 82 pocket gophers and determined their fate; we also located nests and food caches. Sixty-two pocket gophers were successfully monitored through treatment, 40 (64.5%) of which died as a result of the strychnine baiting. We excavated carcasses of 40 radio-equipped and 5 unmarked pocket gophers, located a mean of 48 cm below ground (range = 10 to 152 cm). Most carcasses were located in nests, which had a mean depth of 57 cm. We concluded that strychnine-poisoned gophers presented a negligible risk to grizzly bears because pocket gophers died below ground, usually separate from each other, and carcasses contained only small amounts of strychnine ($\bar{X}$ = 0.16 mg).

In this study, risk assessment was greatly enhanced by use of radiotelemetry. Assessing risks to the low density, mobile population of chipmunks was possible because of radiotelemetry, even though numbers monitored were low. Use of radiotelemetry provided data on where pocket gophers died, levels of strychnine residues in poisoned animals, location and quantity of bait stored by pocket gophers, and levels of strychnine on recovered bait, allowing a good assessment of risks to grizzly bears. Without radiotelemetry, finding dead pocket gophers, nests, and food caches would have been possible only by excavating entire burrow systems.

## Hazards to pheasants and cottontail rabbits associated with zinc phosphide baiting for microtine rodents in orchards

Throughout the United States, microtine rodents cause extensive overwintering damage to orchards by girdling and killing trees. Zinc phosphide is used extensively to control microtine rodent populations and reduce damage. Zinc phosphide is an inorganic acute rodenticide that reacts in the gastrointestinal tract of poisoned animals to form the toxic gas phosphine. The LD50 values of zinc phosphide for mammals range from 5.6 to 93 mg/kg and for birds range from 7.5 to 67.4 mg/kg (Johnson and Fagerstone 1994).

DWRC scientists evaluated the hazards associated with surface zinc phosphide baiting for controlling microtine rodents, the meadow vole *(Microtus pennsylvanicus)* and the prairie vole *(M. ochrogaster)*, in orchards in southwestern Michigan (Hegdal unpublished data). During late October and early November 1975, landowners treated about 385 ha of orchards with 2% zinc phosphide bait at 5.6 and 11 kg/ha using aerial and ground-broadcast treatments. Application rates varied between 11 kg/ha for aerial treatments and 5.6 to 11 kg/ha using ground broadcasting. The efficacy of treatment on voles was measured by randomly selecting 5 study plots each in treated and control apple orchards and trapping before and after treatment. Only 1 of the plots had a high enough vole population to make the population reduction estimate statistically valid; percent reduction on this plot was 88.5%.

Two nontarget species were thought to be at greatest risk from the treatment and were chosen for intensive study. Cottontail rabbits were thought to be at risk based on potential exposure to the cracked corn bait, and pheasants had low LD50s of 8.8 to 26.7 mg/kg (Johnson and Fagerstone 1994). Radiotelemetry was used to assess risk to both species because they are difficult to observe or census in other ways. We were able to radio equip only 8 cottontail rabbits because other available food made trapping difficult. Four of those rabbits used treated areas, survived the treatment, were tracked for 16 to 40 d, then were collected and analyzed for residues; 1 of the 4 contained low zinc phosphide residues (0.03 ppm). During carcass searches on 272 ha, we found 8 dead cottontail rabbits (0.03/ha); the 4 that could be analyzed for zinc phosphide contained residues of 0.28 to 6.2 ppm in the gastrointestinal tracts. In addition, 3 of 5 cottontail rabbits shot in and near treated areas after treatment were positive for zinc phosphide residues (< 0.01 to 0.38 ppm). These data suggest cottontail rabbits were consuming sublethal levels of bait. However, 34 live rabbits were observed during carcass searches. Because so few rabbits were fitted with transmitters and rabbit densities before and after treatment could not be estimated, the effects of zinc phosphide on rabbit populations could not be quantified. However, populations did not appear to be seriously affected.

Using night spotlighting, we captured and radio equipped 25 pheasants with a backpack transmitter. Pheasants were tracked for up to 42 d using both hand-held and truck-mounted antennas; only 1 pheasant was killed by the zinc phosphide bait. Another 4 were killed by predators, 7 were shot by hunters, contact was lost with 3 (one of which survived for 13 months until it was shot by a hunter), and 6 did not use treated areas after treatment; none of these birds analyzed contained zinc phosphide residues. Five radio-equipped pheasants were tracked in treated areas after treatment. One was found dead 3 d posttreatment and was probably killed by the bait because it contained 2.0 ppm zinc phosphide in the gastrointestinal tract; the other birds were collected after treatment and contained no trace of zinc phosphide, nor did 9 other pheasants collected by shooting after treatment. No dead pheasants were found during carcass searches, although 14 live pheasants were observed. Although risks to pheasants were not quantified, they appeared minimal.

Carcass searches were conducted on 272 ha between 1 and 14 d after treatment to assess risk to species not radio equipped. Six deermice *(Peromyscus maniculatus)* were found dead or dying and contained residues of 0.24 to 69 ppm. One blue jay *(Cyanocitta cristata)* contained 0.83 ppm zinc phosphide. Of special interest is the lack of mortality in northern bobwhite *(Colinus virginianus)*, which are very sensitive to zinc phosphide (LD50 = 12.9 mg/kg) (Johnson and Fagerstone 1994). During carcass searches 37 flocks of quail were observed, but no quail were found dead; 2 of 4 apparently healthy live birds captured after treatment contained residues of 0.06 and 11 ppm, indicating that sublethal exposure to the bait had occurred. None of 4 mourning doves collected after treatment contained residues. Although it is clear that exposure can occur, risk to seed-eating and gallinaceous bird populations from orchard baiting with zinc phosphide appears to be minimal.

We concluded that zinc phosphide-treated bait can effectively be used in orchards with relatively low risk. A few small mammals, cottontail rabbits, pheasants, and perhaps other birds are likely to be killed, but populations will not be significantly reduced.

This study relied on a variety of techniques to assess risk. Telemetry was very successful for pheasants, but less so for cottontail rabbits, which could not be captured easily. Researchers were forced to rely on more conventional techniques such as carcass searches to provide a risk assessment.

## Hazards to wildlife associated with 1080 baiting for California ground squirrels

Of the 5 studies discussed in this chapter, the following study was the most comprehensive in terms of the variety of species monitored and the magnitude of telemetry use. The objectives of this study were to evaluate the primary and secondary risks to nontarget wildlife of an operational program using 1080-treated grain bait to control California ground squirrels. Compound 1080 is an acutely toxic rodenticide with LD50s to mammals of 0.1 to 60 mg/kg and birds of 2.0 to 20 mg/kg (Azert unpublished data).

The study was conducted in the foothills of the Sierra Nevada in Tulare County, California. In June 1977, 0.075% 1080-treated grain was applied by aerial application on about 25,000 ha of rangeland to control ground squirrel populations (Hegdal et al. 1986); the entire area was considered the treatment area. Four methods were used to evaluate the efficacy of 1080 grain bait on California ground squirrels (Hegdal et al. 1986): closed-hole, marked population survival, total population survival, and radiotelemetry. On 5 treated plots, mean ground squirrel reduction was 85%: 64.6% using closed-hole activity indices, 92.2% using marked ground squirrel survival, 84.1% using total ground squirrel survival, and 90% using radiotelemetry. Radiotelemetry and marked population survival probably provided the most accurate estimates. After treatment, 38 ground squirrels (2.8/ha) were found dead on the surface of the 5 ground squirrel plots. During off-plot carcass searches, 294 ground squirrels were found dead on the surface of 381.1 ha searched (0.8/ha), indicating that secondary exposure to raptors and mammalian predators could occur.

Radiotelemetry was the main technique used to assess risk to nontarget birds and mammals by monitoring movement and mortality of radio-equipped animals in and around treated areas. The radio-tracking system employed a beacon transmitter, numbered tracking stations, and mobile radio-tracking vehicles equipped with dual yagi antennas and voice radio communications systems. Animal locations were determined by triangulation. Motion sensitive mortality transmitters were used to detect deaths of larger predators. Mortality of other radio-equipped animals was detected by lack of movement of the transmitter signal and obtaining visual sightings of animals.

Mourning doves and California quail *(Callipepla californica)* were selected as representative species for assessment of risks to seed-eating birds. Twenty-one mourning doves and 3 California quail were equipped with transmitters. Although doves and quail visited treated areas and some were observed picking up 1080-treated bait, all survived the baiting. Doves readily consume oats (Hegdal unpublished data) and dove LD50 values are low enough (8.6 to 14.6 mg/kg) to cause mortality (S. P. Atzert, unpublished review of sodium monofluoroacetate—its properties, toxicology, and use in predator and rodent control, U.S. Department of the Interior, U.S. Fish and Wildlife Service), so either 1080 acts as a repellent to seed-eating birds or as an emetic. Only 1 seed-eating bird carcass (Brewer's blackbird) was found that was considered to be a treatment-related mortality, and it contained 1080 residues (0.2 ppm). Therefore, risks to seed-eating birds appeared minimal.

As in the studies previously discussed, secondary hazards to mammalian predators were evaluated using radiotelemetry. Five of 6 radio-equipped coyotes and 3 of 9 radio-equipped bobcats *(Lynx rufus)* died after treatment. Other radio-equipped mammalian predators (2 raccoons, 3 badgers, and 3 striped skunks) survived treatment, although 3 skunks were found dead during carcass searches, indicating a potential risk to that species. In addition, a domestic cat and dog died near treated areas. Although analytical methods were not available for measuring secondary toxicity when this study was conducted, the observed mortality indicated that mammalian predators, particularly canids, were very susceptible to secondary poisoning.

In contrast to the mammalian secondary mortalities, no treatment-related mortalities were observed while monitoring 9 radio-equipped raptors and carrion-eating birds, including 3 red-tailed hawks, 1 golden eagle *(Aquila chrysaetos)*, 1 great horned owl, 2 turkey vultures *(Cathartes aura)*, and 2 common ravens *(Corvus corax)*, or while monitoring 58 active raptor nests. Despite exposure to poisoned ground squirrels on the surface of the ground, and dead ground squirrels found in nests, raptors were not affected by 1080.

Carcass searches were conducted beginning the day of treatment and continuing for 2 weeks after treatment to assess mortality to small mammals and to determine whether any unanticipated nontarget animals might be susceptible to 1080 poisoning. During carcass searches on 381 ha, we found 15 Heermann's kangaroo rats *(Dipodomys heermanni)*, 8 little pocket mice *(Perognathus longimembris)*, 4 desert woodrats *(Neotoma lepida)*, 4 deermice, and 1 western harvest mouse *(Reithrodontomys megalotis)*. Residues in carcasses ranged from nondetectable to 76 ppm. Eleven desert cottontails *(Sylvilagus audubonii)* were found during carcass searches (residues ranges from nondetectable to 20 ppm), and 55 live rabbits were observed. The carcass searches showed that the 1080 bait presented primary poisoning risks to nontarget rodents and rabbits but did not allow for quantification of those risks because densities of animals were not known. The data do indicate that 1080 should not be applied in areas where there are endangered rodents and lagomorphs of concern.

An unexpected finding was some risk to insectivorous birds—1 acorn woodpecker *(Melanerpes formicivorus)*, 2 white-breasted nuthatches *(Sitta carolinensis)*, and 1 ash-throated flycatcher *(Myiarchus cinerascens)* were found during carcass searches (1080 residues ranged from nondetectable to 4.4 ppm). The birds had apparently been feeding on poisoned ants which contained 1080 residues.

## Advantages and problems of using radiotelemetry for nontarget hazards assessment

The 5 studies discussed in this chapter illustrate many of the advantages and problems inherent with the use of radiotelemetry to monitor nontarget hazards. Advantages of radiotelemetry were many:

1) We were able to assess movement and mortality of animals that were highly mobile, secretive in nature or nocturnal, and for which adequate census means do not exist. These included large seed-eating bird species, raptors, mammalian predators, and nocturnal or burrowing mammals.
2) Telemetry allowed us to assess exposure by determining if and how much instrumented animals actually used treated areas.
3) Telemetry allowed recovery of carcasses for residue analysis to confirm cause of death.
4) Use of radiotelemetry can sometimes better define risk than laboratory LD50 data. For example, LD50 values for raptors with 1080 were generally low (about 10 mg/kg) and some risk was anticipated, yet raptors proved to be relatively immune to 1080 poisoning in field situations, possibly because they regurgitated poisoned tissue.
5) Home range and movement information developed before and after treatment could be compared to assess behavioral changes that may have occurred as a result of sublethal pesticide exposure.

There are some problems inherent with the use of radiotelemetry to assess risk. These include proper species determination (what species are at risk), transmitter design, sample size, determination of the cause of mortality, and economic costs.

### *Species at risk*

It is difficult to determine the wildlife species with greatest risk of pesticide exposure (and therefore targeted for intensive monitoring) without first obtaining adequate laboratory or LD50 data or having conducted a screening field test. For example, no data were available on the sensitivity of insectivorous birds to 1080 secondary poisoning, so potential hazards to these species could easily have been missed if not for the extensive carcass searches. Information on wildlife food habits and life histories is also important when determining the species to target for exposure and mortality monitoring during field studies. Three decisions made prior to initiating the studies discussed in this chapter illustrate this importance:

1) In the zinc phosphide orchard study, pheasants were known to be sensitive to zinc phosphide, were assumed to be at great risk, and were intensively monitored; however, few birds actually used the orchard habitat, preferring the weedy field borders instead.

2) California quail in the 1080 study were thought to be a good indicator species for monitoring seed-eating bird mortality; but during the late spring and early summer, quail did not consume seeds or grain baits and were therefore not exposed to the 1080 treatment.
3) In the strychnine pocket gopher study in western forests, chipmunks were identified prior to the study as a representative small mammal at risk from exposure to underground strychnine baits. However, they did not appear to forage extensively in the clearcuts; a later study (Anthony et al. 1984) showed greater risk to golden-mantled ground squirrels *(Spermophilus lateralis)*, a species not monitored in this study.

### *Transmitter reliability*

A second problem with use of radiotelemetry is that transmitters are often unreliable for monitoring animals over periods long enough to assess hazards because of inadequate attachment techniques, size, and short signal longevity. Attachment of transmitters is difficult, particularly when applying them to birds. In these studies, we used harnesses, transmitters glued onto rubber patches that were then glued onto clipped feathers, tail clips, and other methods (Hegdal and Gatz 1976; Hegdal et al. 1986). Some methods caused abrasion of the skin; others allowed the transmitters to come off as feathers were molted or glue disintegrated.

Transmitter size is often a problem for small bird and mammal species, forcing use of transmitters as small as 1 to 2 g. It is common practice to limit transmitter weight to no more than 5% of a mammal's or 2 to 3% of a bird's weight (A. L. Kolz, personal communication). Even with small transmitters we have observed high mortality levels in pocket gophers and small birds, probably caused by transmitter weight. The process of instrumenting an animal could potentially make that animal more susceptible to pesticide effects or potentially cause behavioral responses that could attract predators. Therefore, transmitter-induced mortality makes it difficult to interpret risk data and forces the use of control areas when working with radio-equipped animals.

Longevity of the transmitter is a concomitant problem; because of size limitations for small bird and mammal transmitters, battery longevity may be only 2 or 3 weeks. Small bird transmitter batteries may fail after 1 week or 10 d. Few pesticide field studies can adequately assess risk within this short timeframe.

### *Sample size*

Field risk assessment studies inherently suffer from sample size problems for several reasons: 1) initial populations of the animals targeted for monitoring may not be large, particularly for species with large territorial home ranges such as mammalian predators and raptors—in the California 1080 study, we were able to trap only 6 coyotes on the 90,000 ha study area; 2) trapping is frequently difficult—again, especially with predators and raptors—and requires experienced personnel and much time; 3) predator losses and migration can be significant for certain species and during certain times of the year; in the studies discussed, predator and migration losses often reduced the sample size monitored through treatment baiting, particularly for migratory birds, by at least 50%; and 4) when baiting occurs only in portions of the study area (such as in the zinc phosphide orchard study or strychnine pocket gopher studies), many of the radio-equipped animals may not use treated areas, further reducing sample size of exposed animals. For these reasons, it is difficult to obtain statistically acceptable sample sizes of transmittered animals.

### *Residue analysis*

Determination of whether the pesticide contributed to mortality is not always easy, particularly when transmitters exert an effect on animals; therefore, a validated analytical method for animal tissue residues is necessary. In the 1080 study, the lack of adequate analytical methods for 1080 metabolites prevented us from stating conclusively that 1080 caused mortality to mammalian predators.

### *Cost and staff*

A final problem with radiotelemetry studies is the high cost of equipment and staff. Transmitters and receivers are expensive and radiotelemetry studies are labor intensive. The studies described in this chapter would cost a minimum of $250,000 to $500,000 to conduct now. If multiple study sites were required, the cost would be multiplied accordingly.

Despite the many advantages of radiotelemetry, the problems listed above demonstrate the importance of using multiple means for assessing risk. Carcass searches, radiotelemetry, or other assessment techniques when used alone have been generally inadequate for developing quantitative risk assessments (RESOLVE 1994). The preceding studies show that when several techniques are used in combination, the risk assessment is greatly improved.

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